

LENS
Measuring the
Neutrino Luminosity of the Sun

Homestake Lab Workshop
Lead, SD
February 10, 2005

Christian Grieb
Virginia Tech

LENS-SOI / LENS-Cal Collaboration

(Russia-US: 2004-)

Russia:

INR (Moscow): I. Barabanov, L. Bezrukov, V. Gurentsov,
V. Kornoukhov, E. Yanovich;

INR (Troitsk): V. Gavrin et al., A. Kopylov et al.;

U. S.:

BNL: A. Garnov, R. L. Hahn, M. Yeh;

U. N. Carolina: A. Champagne;

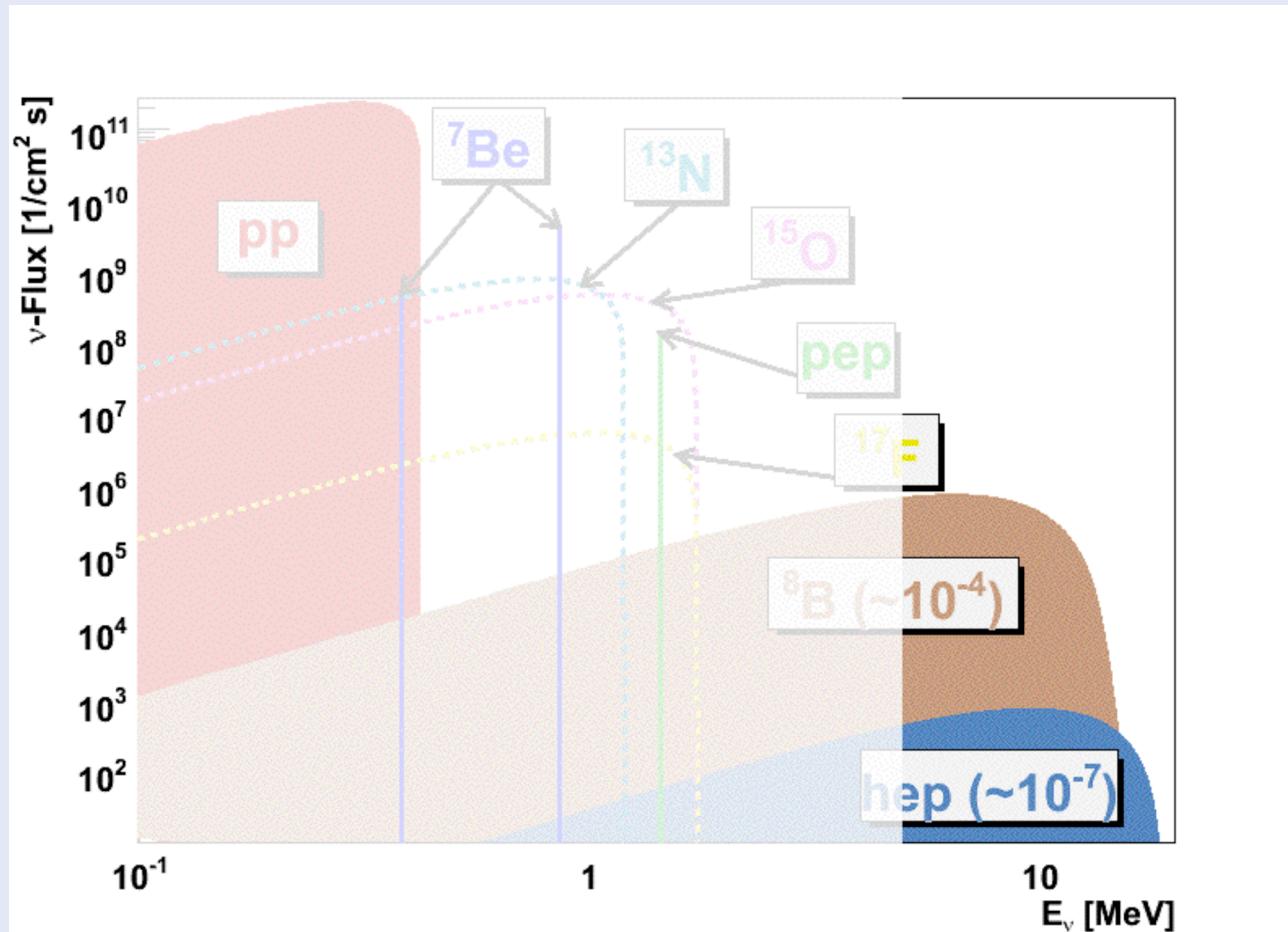
ORNL: J. Blackmon, C. Rasco, A. Galindo-Uribarri;

Princeton U. : J. Benziger;

Virginia Tech: Z. Chang, C. Grieb, M. Pitt,
R.S. Raghavan, R.B. Vogelaar;

LENS-Indium: SCIENCE GOAL

Precision Measurement of the Neutrino Luminosity of the Sun



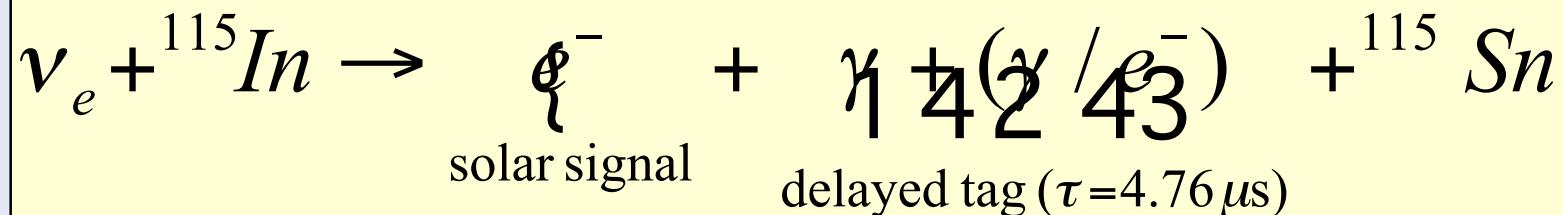
Spectral data only above 5 MeV (10^{-4} part of total flux)

LENS-Indium: SCIENCE GOAL

Precision Measurement of the Neutrino Luminosity of the Sun

Measure the low energy solar ν spectrum (pp, ^7Be , CNO)

- ◊ $\pm \sim 3\%$ pp- ν flux
- ◊ Experimental tool: Tagged CC Neutrino Capture in Indium



- ◊ Problem of ^{115}In beta-decay background under control

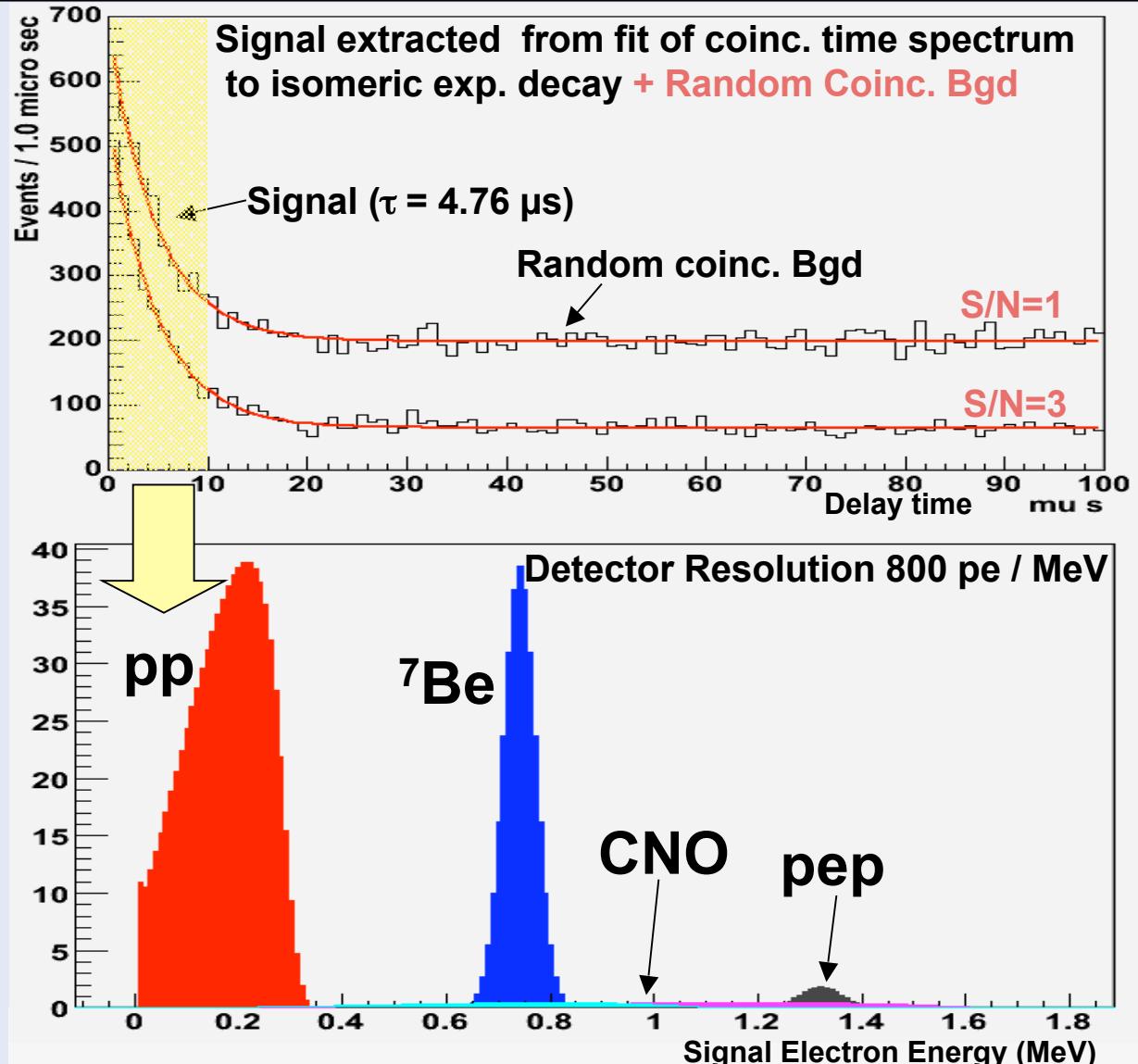
Expected Result: Low Energy Solar Neutrino Spectrum

LENS-Sol Signal
 =
SSM(low CNO) + LMA
 x
Detection Efficiency ϵ

pp: $\epsilon = 64\%$
 ^7Be : $\epsilon = 85\%$
 pep: $\epsilon = 90\%$

- ◊ Rate: pp 40 /y/t ln
- ◊ 2000 pp ev. / 5y $\pm 2.5\%$
- ◊ Design Goal: S/N ≥ 3

**Access to pp
spectral *Shape* for
the first time**



NEW SCIENCE - Discovery Potential of LENS

In 5 years:

- ◊ Absolute pp, ^7Be nu fluxes at earth $\pm 3\%$
- ◊ Measured Neutrino Luminosity ($\sim 4\%$)

Photon Luminosity _ Neutrino Luminosity

Ultimate test of the neutrino & the sun

Experimental status - No useful constraint:

$$L_{\nu(\text{inferred})} / L_{h\nu} = 1.4 \begin{pmatrix} 0.2 \\ 0.3 \end{pmatrix}_{\sigma} \begin{pmatrix} 0.7 \\ 0.6 \end{pmatrix}_{3\sigma}$$

- ◊ Test solar model and neutrino oscillations with one measurement
- ◊ Astrophysics: $L_{\nu} > L_{h\nu}$ Is the sun getting hotter?
 $L_{\nu} < L_{h\nu}$ Cooling or a sub-dominant non-nuclear source of energy in the sun?
- ◊ Precision values of $_{12}, _{13}$; Sterile Neutrinos?

NEW SCIENCE - Discovery Potential of LENS

APS Nu Study 2004◊ Low Energy Solar Nu Spectrum: one of 3 Priorities

In 2 years:

- **Test of MSW LMA physics** - *no specific physics proof yet !*
 $P_{ee}(\text{pp})=0.6$ (vac. osc.) $P_{ee}(^8\text{B})=0.35$ (matter osc.), as predicted?
- **Non-standard Fundamental Interactions?**
Strong deviations from the LMA profile of $P_{ee}(E)$?
- **Mass Varying Neutrinos?**
(see above)
- **CPT Invariance of Neutrinos?**
so far LMA only from Kamland $\bar{\nu}_e$, is this true
also for ν_e ?
- **RSFP/ Nu magnetic moments**

Time Variation of pp and ${}^7\text{Be}$ signals? (No Var. of ${}^8\text{B}$ nus !)
(Chauhan et al JHEP 2005)

**Low Energy
Neutrinos:
Only way to
answer these
questions !**

In-LENS: Studied Worldwide Since 1976!

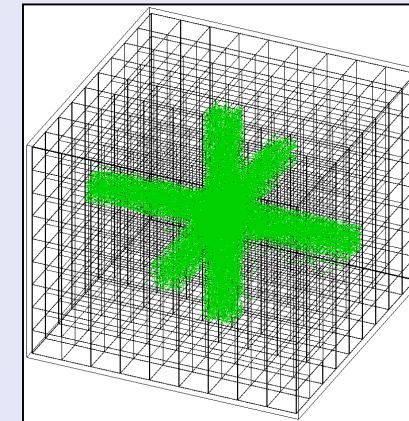
Dramatic Progress in 2005

Status Fall 2003

- In Liq. Scintillator
- New Detector Design
- Full Bgd Structure Simulation
- New Analysis Strategy

(

Status Fall 2005



Longit. modules + hybrid (InLS + LS)

InLS: 5% In, $L(1/e)=1.5m$, 230 pe/MeV

Total mass LS: 6000t

In: 30t for 1900 pp ν's /5y

PMTs: ~200,000

pp-ν Detection Efficiency: ~20%

S/N~1 (single decay BS only)

~1/ 25 (All In decay modes)

(MPIK Talk at DPG 03/2004)

Cubic Lattice Non-hybrid (InLS only)

InLS: 8% In, $L(1/e)>10m$, 900 pe/MeV

Mass InLS : 125t to 190t

In: 10t-15t for 1970 pp ν's /5y

PMTs: 13,300 (3") - 6,500 (5")

pp-ν Detection Efficiency: 64-45%

S/N ~3 (ALL In decay modes)

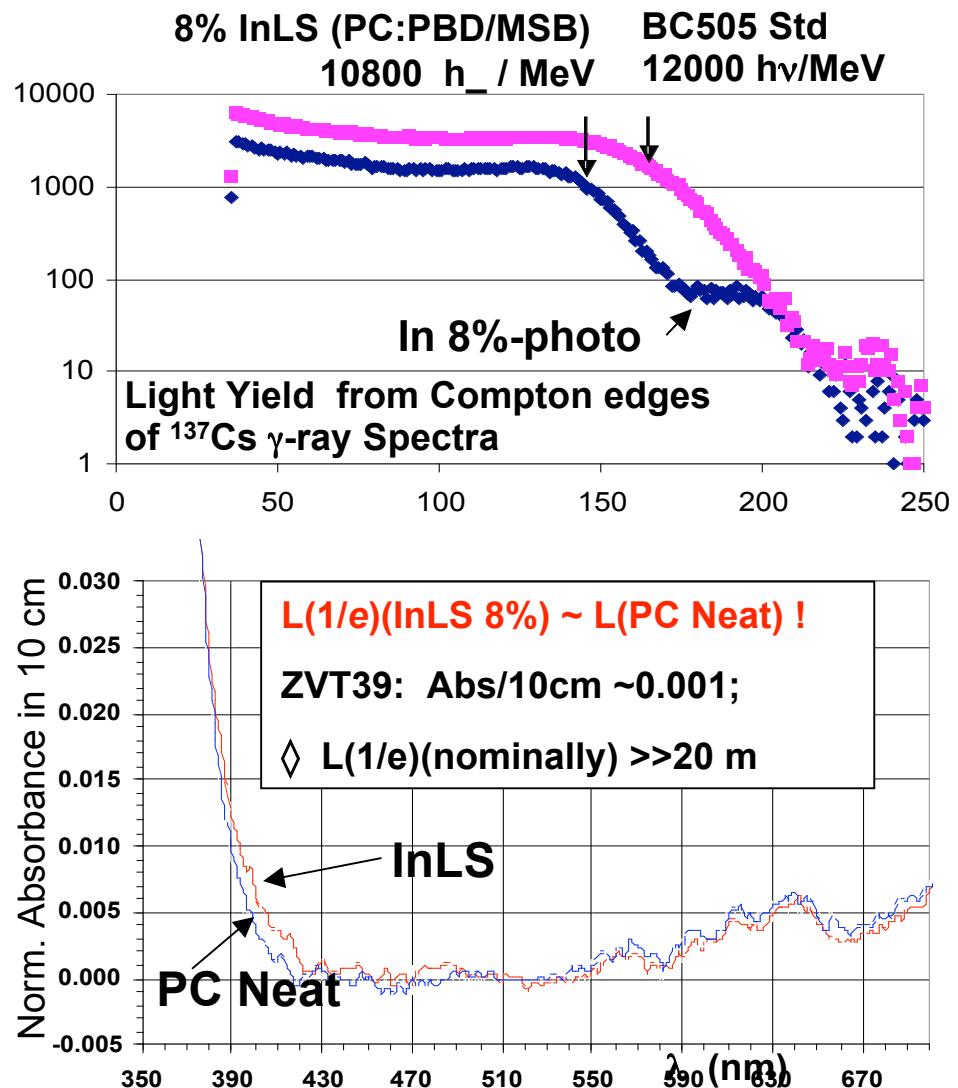
Indium Liquid Scintillator Status

Milestones unprecedented in metal LS technology

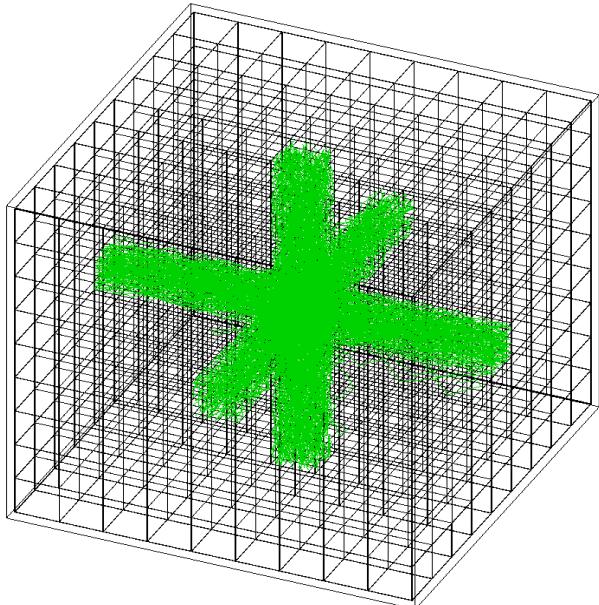
LS technique relevant to many other applications

1. Indium concentration ~8%wt (higher may be viable)
2. Scintillation signal efficiency (working value): 9000 hv/MeV
3. Transparency at 430 nm: $L(1/e)$ (working value): 10m
4. Chemical and Optical Stability: at least 2 years
5. InLS Chemistry - Robust

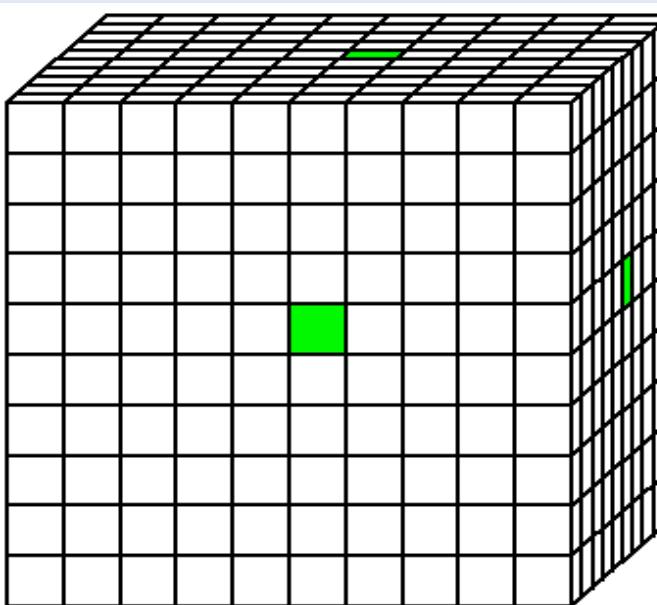
Basic Bell Labs Patent,
filed 2001, awarded 2004



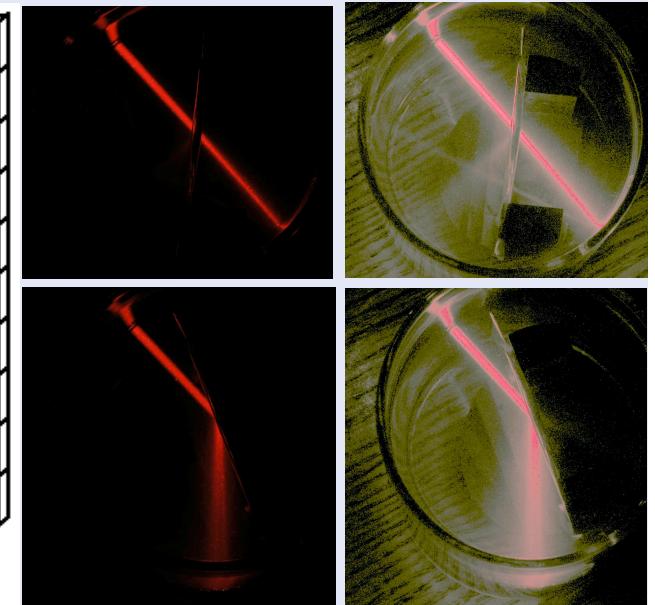
New Detector Concept - The Scintillation Lattice Chamber



Light propagation
in GEANT4



Concept



Test of double foil
mirror in liq. @~2bar

3D Digital Localizability of Hit within one cube

- ◊ ~75mm precision vs. 600 mm ($\pm 2\%$) by TOF in longitudinal modules
- ◊ x8 less vertex vol. ◊ x8 less random coinc. ◊ Big effect on Background
- ◊ Hit localizability independent of event energy

Background Suppression - Analysis of Tag Candidates

	Signal $/y /t \ln$	Bgd tot $/y /t \ln$	Bgd A1 $/y /t \ln$	Bgd A2 $/y /t \ln$	Bgd B $/y /t \ln$
RAW	62.5	79×10^{11}			
Valid tag (Energy, Branching, Shower) in Space/Time delayed coinc. with prompt event in vertex	50	“Free” 2.76×10^5	8.3×10^4	2.8×10^3	1.9×10^5
+ ≥ 3 Hits in tag shower	46	2.96×10^4	2.6×10^4	2.5×10^3	1.4×10^3
+ Tag Energy = 620 keV	44	306	0.57	4.5	293
+ Tag topology	40	13 ± 0.6	0.57	4.0	8.35

- ◊ Tag analysis must suppress Background by $\sim 2 \times 10^4$
- ◊ Sufficient to generate $\sim 4 \times 10^6$ n-tuples for the analysis

Final Result: Overall Background suppression $> 10^{11}$
At the cost of signal loss by a factor ~ 1.6

Typical LENS-Sol Design Figures of Merit – Work in Progress

Scintillator properties:

- InLS: 8% In
- $L(1/e) = 1000\text{cm}$
- $LY(\text{InLS}) = 9000 \text{ h}\nu/\text{MeV}$

Detector Design Figures:

Cell Size mm	Cube size m	Pe yield /MeV	Det Eff %	pp- ν /t ln/y	Bgd /t ln/y	S/N	M (ln)* ton	M (InLS) ton	PMT
75	4	1000	64%	40	13	3	10	125	13300 (3")
125	5	950	40%	26	9	2.9	15.3	190	6250 (5")

MINILENS: Global test of LENS R&D

- **Test detector technology**
 - ◊ Large Scale InLS
 - ◊ Design and construction
- **Test background suppression of In radiations by 10^{-11}**
- **Demonstrate In solar *signal* detection in the presence of high background**

Direct blue print for full scale LENS

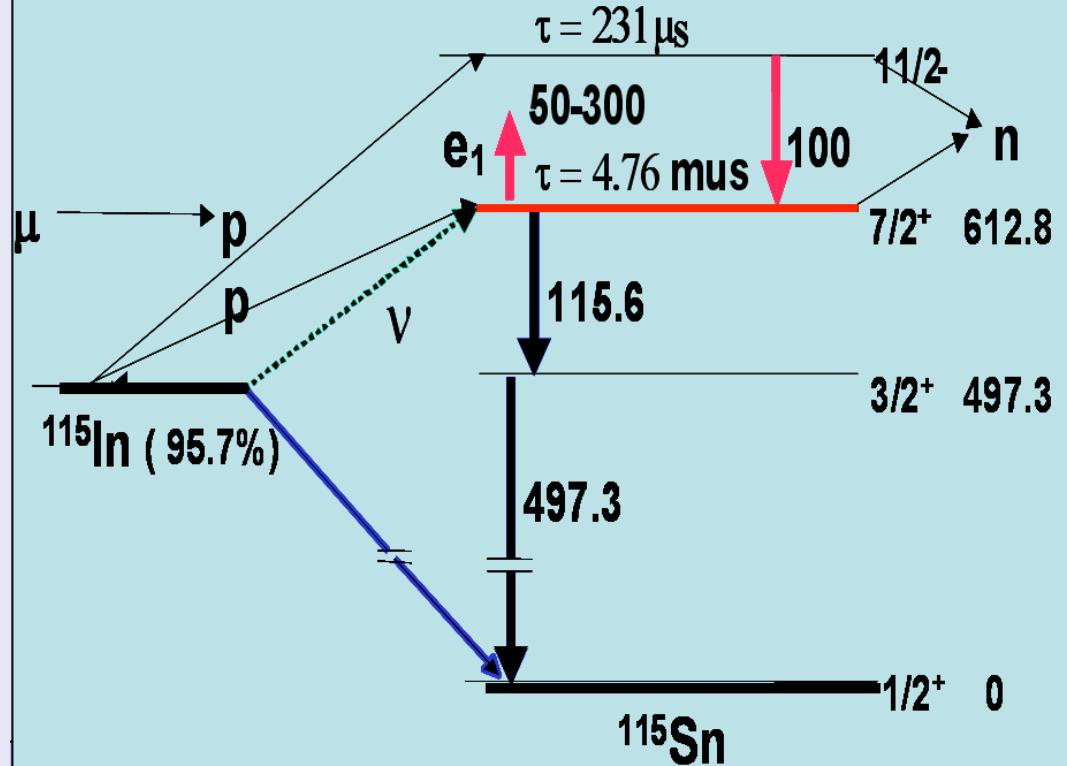
Proxy pp- ν events in MINILENS

Proxy pp nu events in
MINILENS from cosmogenic
 $^{115}\text{In}(\text{p},\text{n})^{115}\text{Sn}$ isomers

- Pretagged via μ , p tracks
- Post tagged via n and 230 μ s delay
- ◊ Gold plated 100 keV events (proxy pp), Tagged by same cascade as In- ν events
- ◊ Demonstrate *In- ν Signal* detection even in MINILENS

Cosmogenic production of In (p,n) Isomers

Taggable via μ , p , n (via In n,gamma) and delayed coincidence
Rate @ 1400 mwe VT-NRL Kimballton lab $\text{I} = 3\text{y/t In}$;
Rate @ surface laboratory: 900 / t In/y



Summary

Major breakthroughs:

- _ In LS Technology
- _ Detector Design
- _ Background Analysis

- ◊ Basic feasibility of In-LENS-Sol secure
 - _ extraordinary suppression of In background
(all other Bgd sources not critical)
 - _ Scintillation Chamber – InLS only
 - _ High detection efficiency ◊ low detector mass
 - _ Good S/N



IN SIGHT: Simple Small LENS (~10 t In /125 t InLS)

Next Step

Test of all the concepts and the technology developed so far:



MINI-LENS - 130 liter InLS scintillation lattice detector

Summary: Key Points

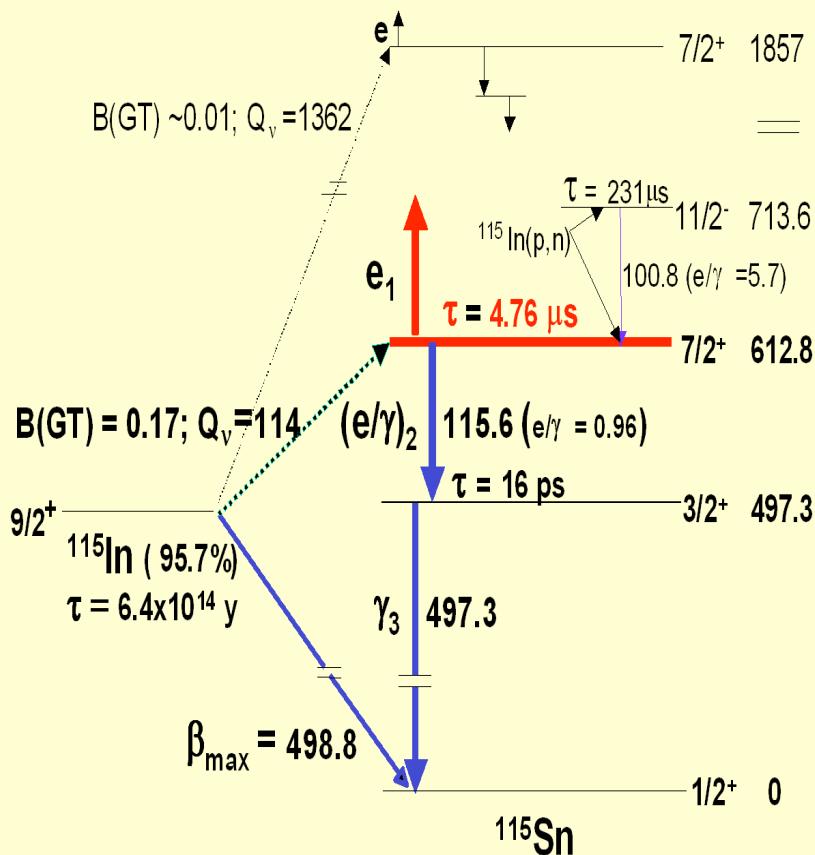
- **Science Goal:**
 - Measure the Solar ν -Luminosity
- **Requirements:**
 - Modest depth requirement > ~2000 mwe due to tagged coincidence measurement
 - ~ 1800m³ for the detector + equal amount for lab space and preparation
- **Readiness:**
 - Sound detector design, technology feasible
 - NSF & DOE proposals submitted (Fall 2005)
 - Next Step: MINILENS
- **Environment and Safety Issues:**
 - ~200t of liquid scintillator

Additional Slides

LENS-Indium: Foundations

CC ν -capture in ^{115}In to excited isomeric level in ^{115}Sn

The Indium Low Energy Neutrino Tag



Tag: Delayed emission of $(e/\gamma) + \gamma$

Threshold: 114 keV \diamond pp- ν 's

^{115}In abundance: $\sim 96\%$

Background Challenge:

- Indium-target is radioactive! ($\tau = 6 \times 10^{14} \text{ y}$)
- ^{115}In -spectrum overlaps pp- ν signal

Basic background discriminator:

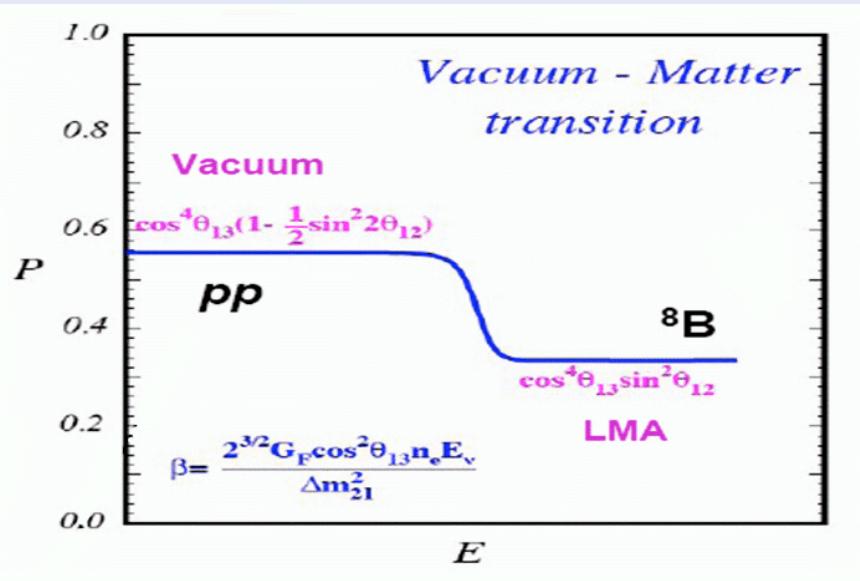
Time/space coincidence tag

Tag energy: $E_{\nu\text{-tag}} = E_{\text{max}} + 116 \text{ keV}$

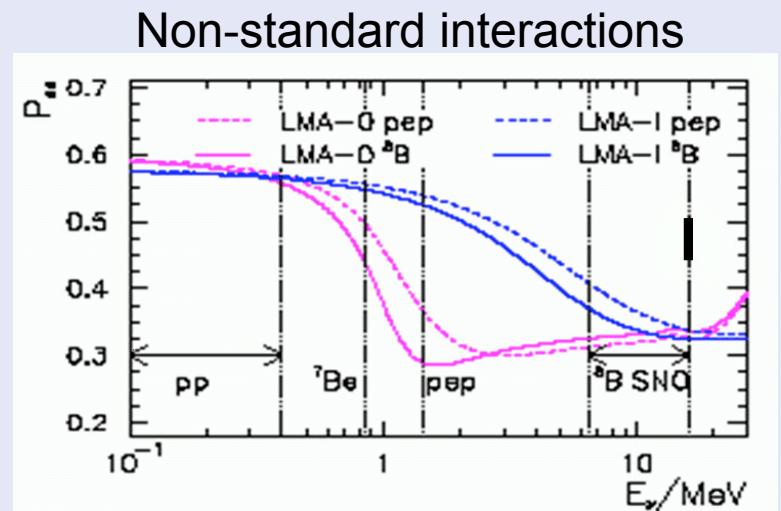
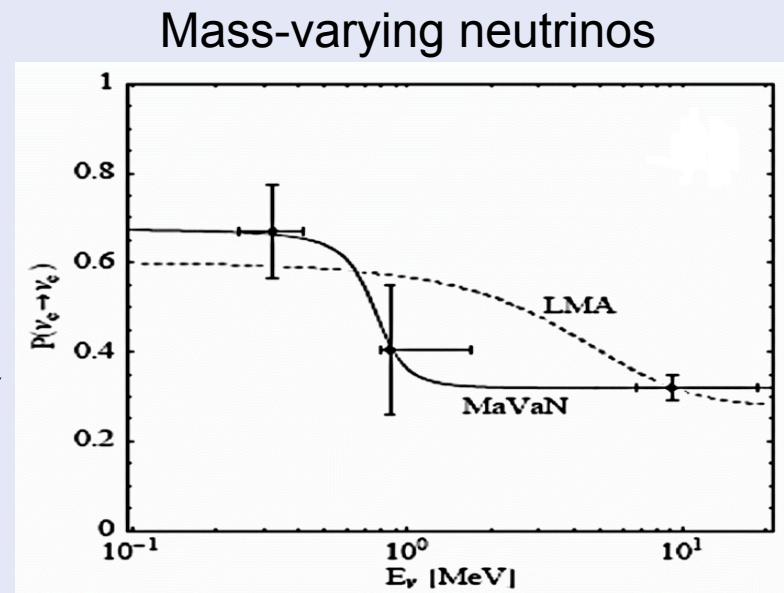
*^7Be , CNO & LENS-Cal signals
not affected by Indium-Bgd!*

Science from Relative Fluxes

MSW-LMA Profile

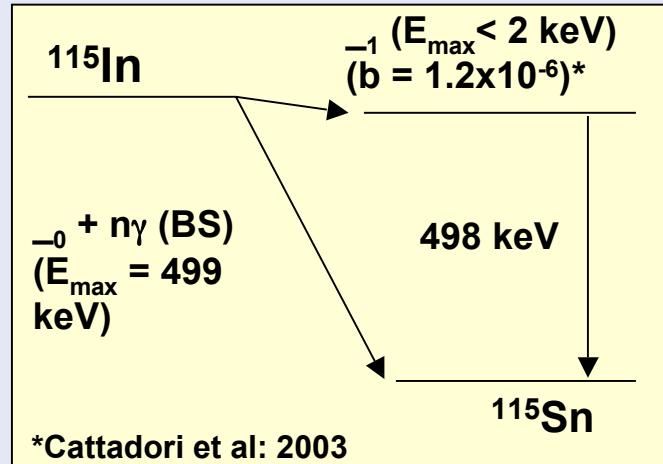


Deviations from standard $P_{\nu_e \rightarrow \nu_e}$
survival probability in various new
scenarios

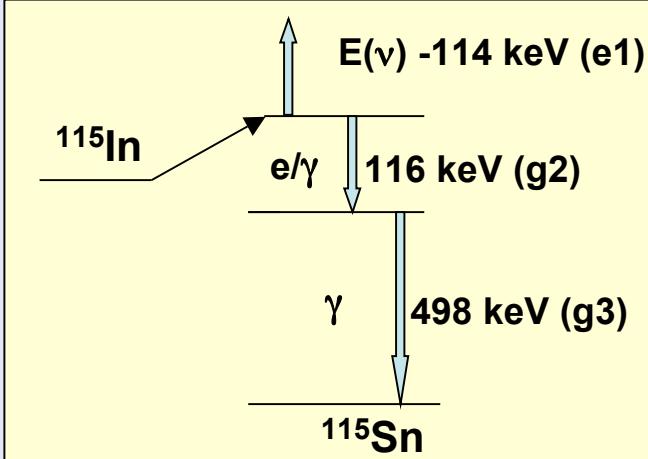


Indium Radioactivity Background

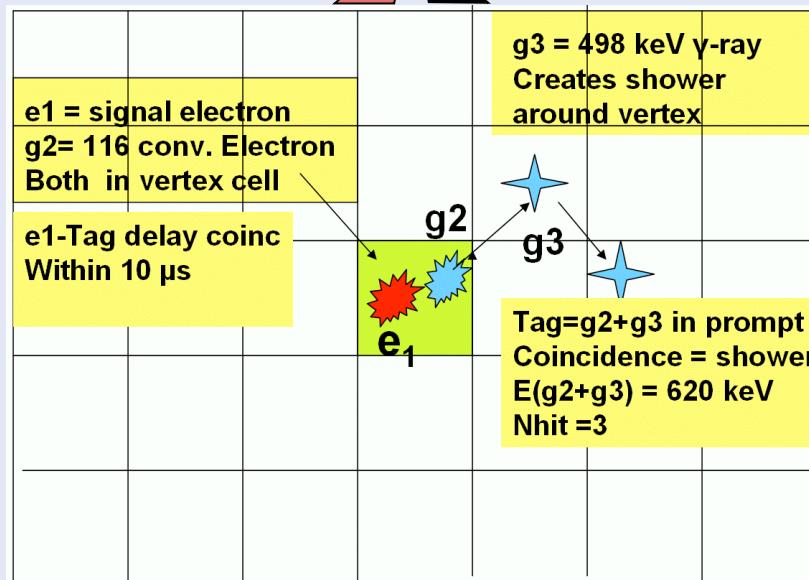
BGD



SIGNAL



Multiple ${}^{115}\text{In}$ decays simulate tag candidate in many ways



Indium Background Simulations and Analysis

Data: Main Simulation of Indium Events with GEANT4

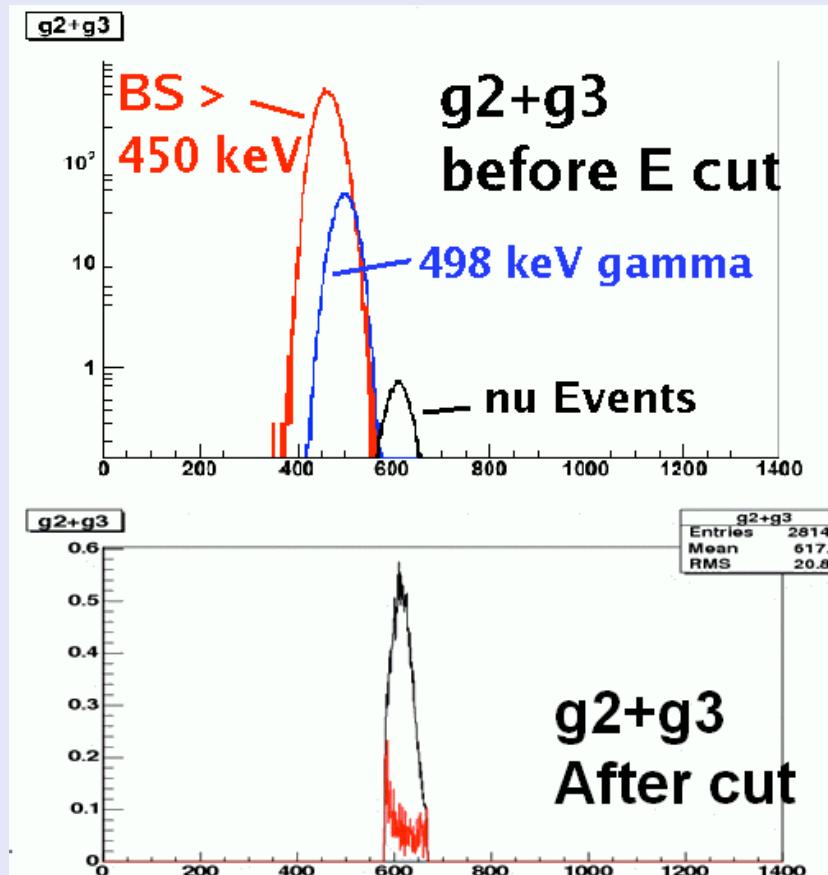
- $\sim 4 \times 10^6$ In decays in one cell centered in $\sim 3\text{m}^3$ volume (2-3 days PC time)
- Analysis trials with choice of pe/MeV and cut parameters (5' /trial)

Analysis Strategy

- Primary selection - tag candidate shower events with $N_{hit} \geq 3$
- Classify all eligible events ($N_{hit} \geq 3$) according to N_{hit}
- Optimize cut conditions *individually for each Nhit class*

Main Cuts

- Total energy: g_2+g_3
- Tag topology: Distance of lone β from shower



Indium Radioactivity Background

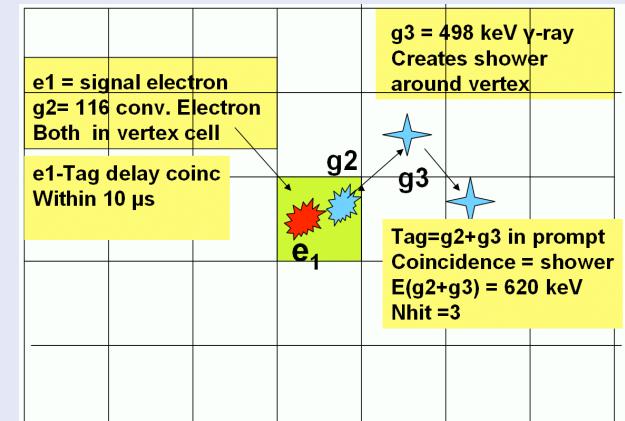
Background categories

n ^{115}In β -decays in (quasi) prompt coincidence produce a tag:

Basic tag candidate: Shower near vertex ($N_{\text{hit}} \geq 3$) - chance coincident with ^{115}In in vertex

Type A: $A_1 = \text{_____} + \text{BS } \gamma (E_{\text{tot}} = 498 \text{ keV}) \text{ (x1)}$ $A_2 = \gamma (498 \text{ keV}) \text{ (x1)}$ } Strong suppression via energy

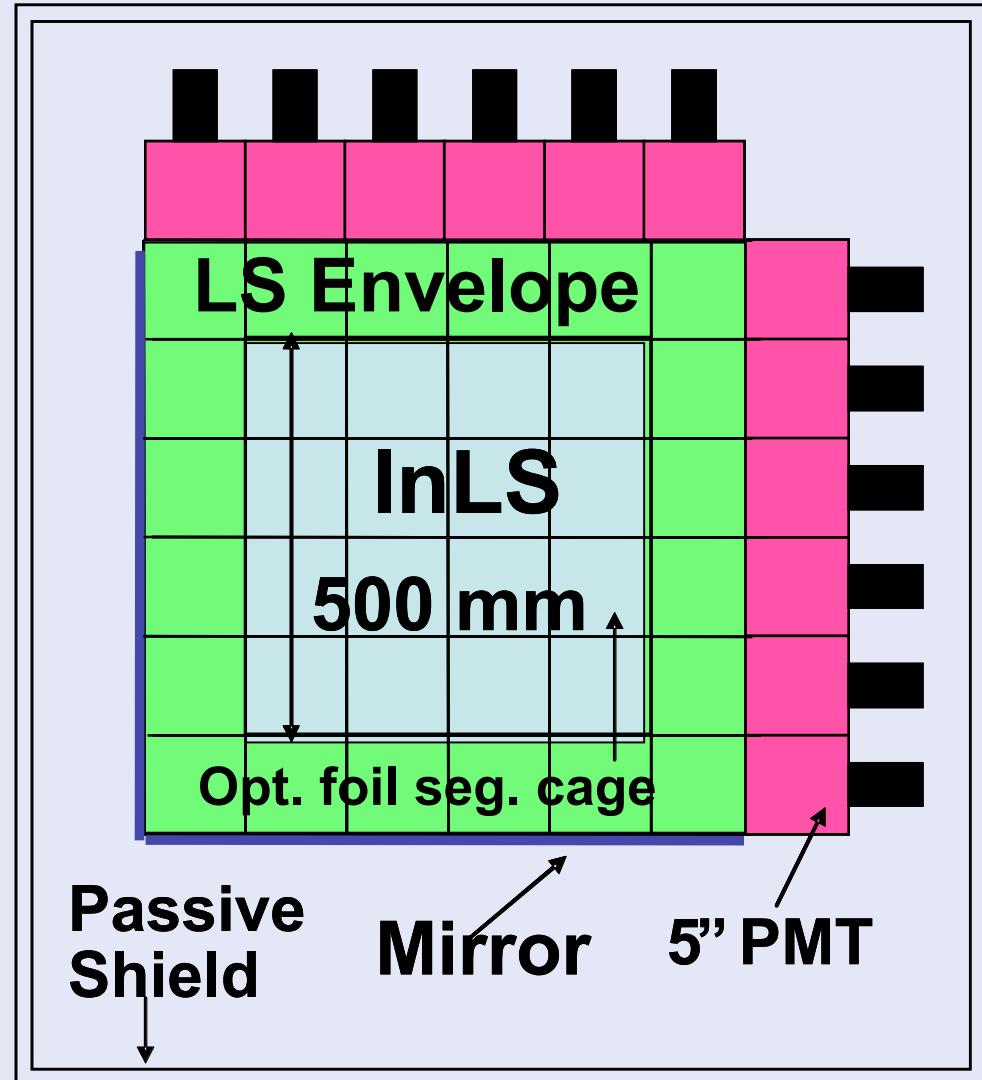
Type B: 2 _-decays (x10⁻⁸)
Type C: 3 _-decays (x10⁻¹⁶)
Type D: 4 _-decays (x10⁻²⁴) } Suppression via tag topology



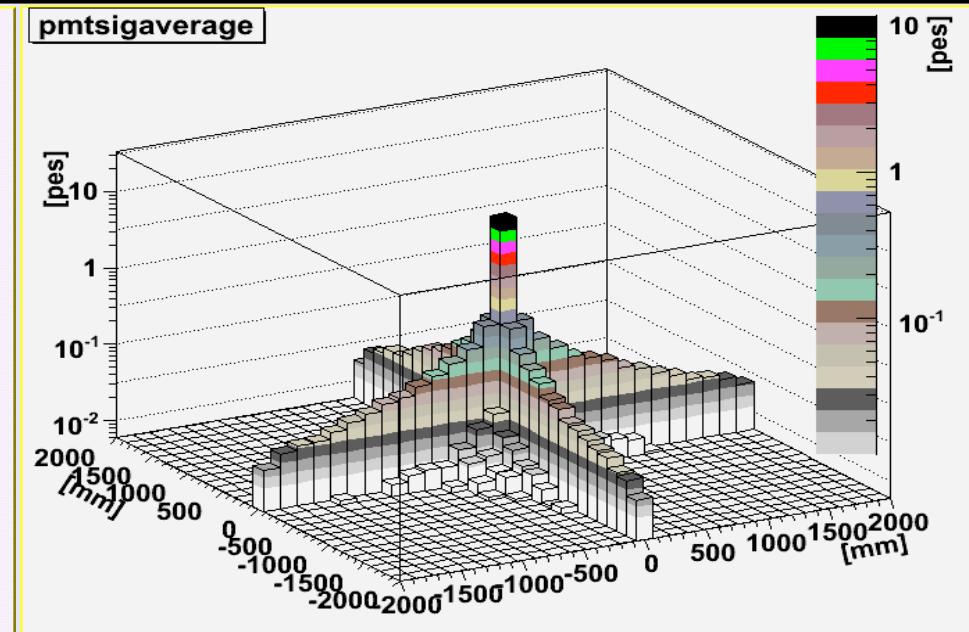
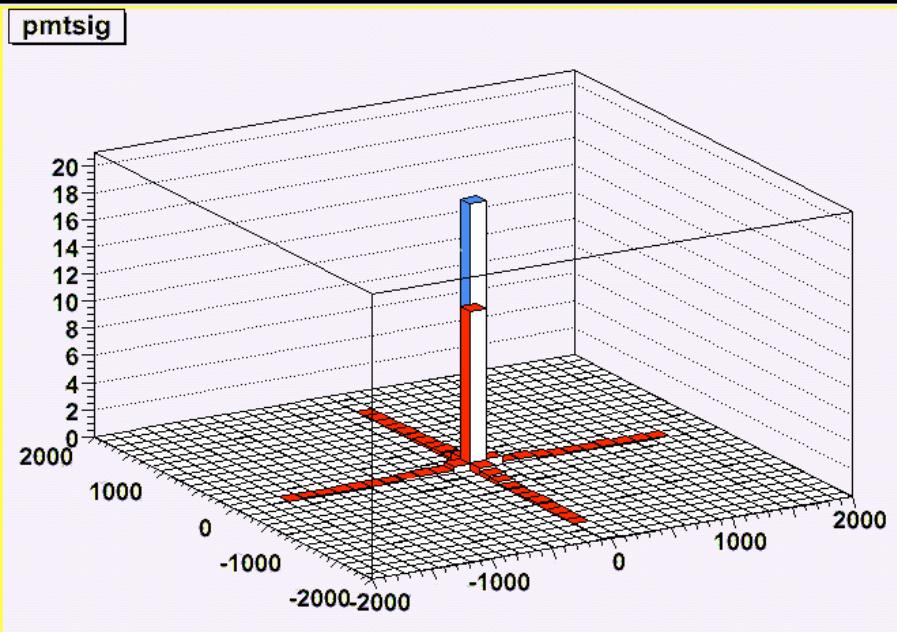
MINILENS

Final Test detector
for LENS

- InLS : 128 L
- PC Envelope : 200 L
- 12.5cm pmt's : 108



Foil Surface Roughness and Impact on the Hit Definition



100 keV event in 4x4x4m cube, 12.5cm cells

Perfect optical surfaces : 20 pe (per channel)

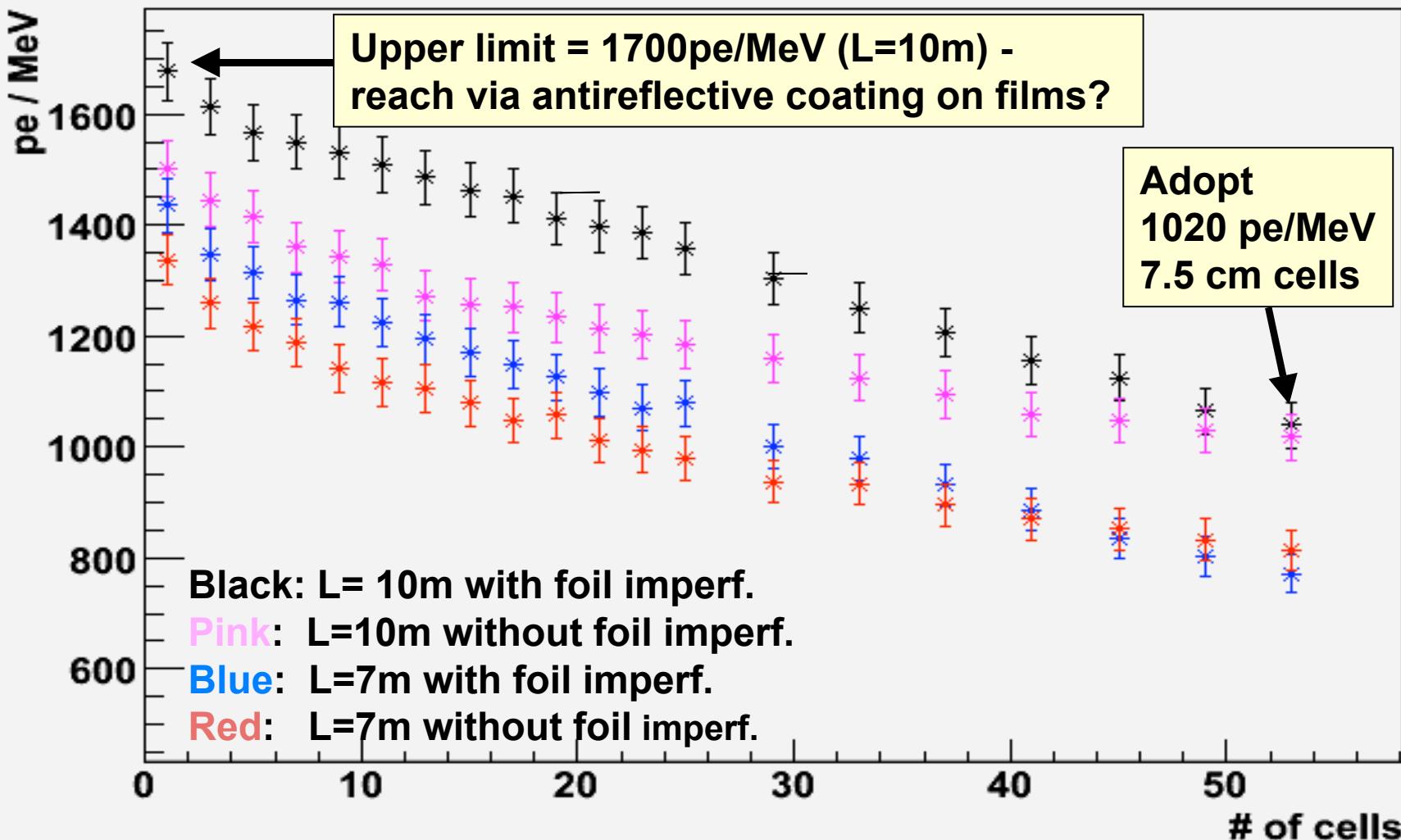
Rough optical surfaces : 20% chance of non-ideal optics at every reflection
12 pe in vertex + ~8 pe in “halo”

Conclusion - Effect of non-smooth segmentation foils:
No light loss - (All photons in hit *and* halo counted)
Hit localization accuracy virtually unaffected

Light loss by Multiple Fresnel Reflection

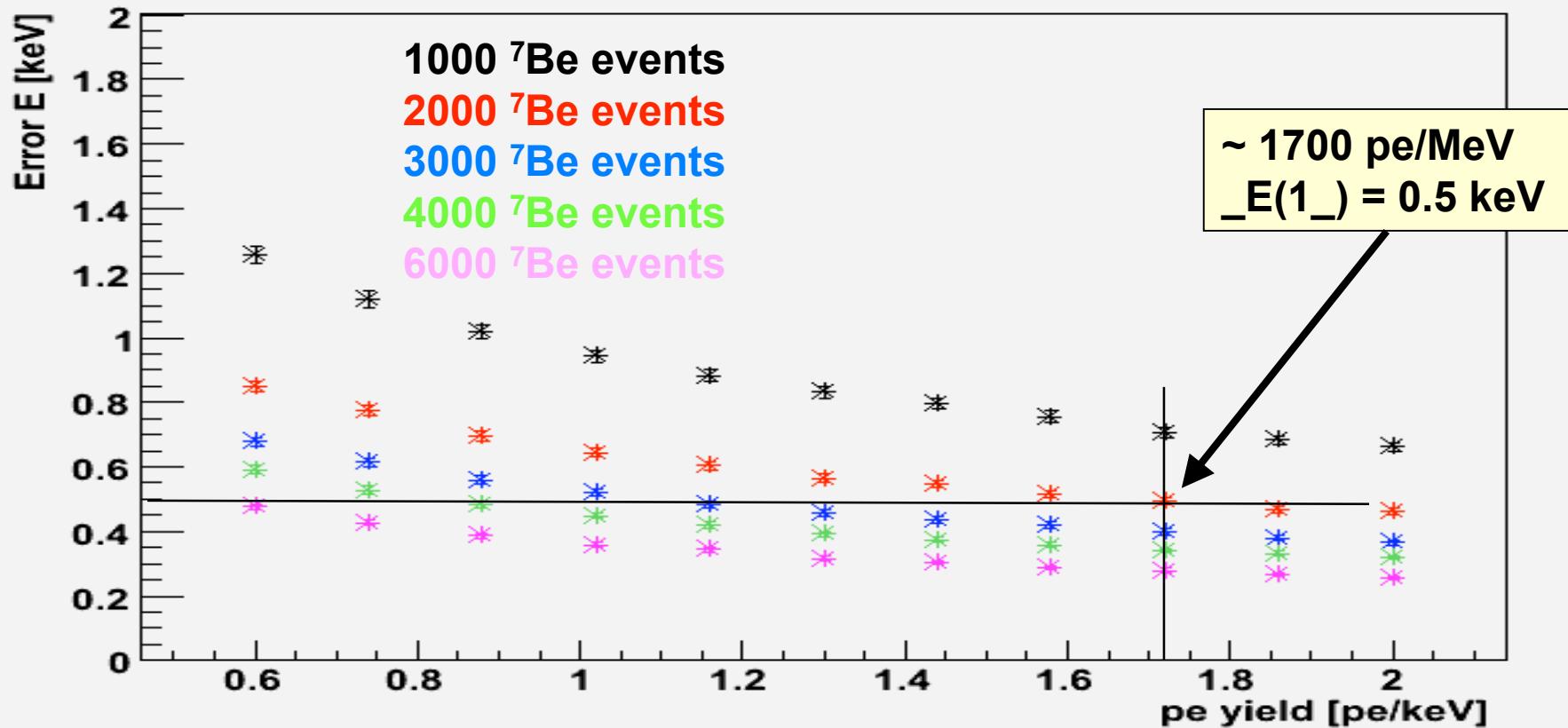
pe yield (400 cm detector)

4x4x4m Cube



Direct Measurement of the Central Temperature of the Sun with High pe/MeV in LENS

Graph



Expected precision of centroid energy of ${}^7\text{Be}$ Line in LENS (*Statistics only*, 2000 events, 1700 pe/MeV): ${}_E(1) \pm 0.5 \text{ keV}$
Predicted solar shift (Bahcall 1993)) ${}_E = + 1.29 \text{ keV}$